3D AERODYNAMIC LOAD CALCULATION ON A HORIZONTAL AXIS WIND TURBINE USING PIV.

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Abstract

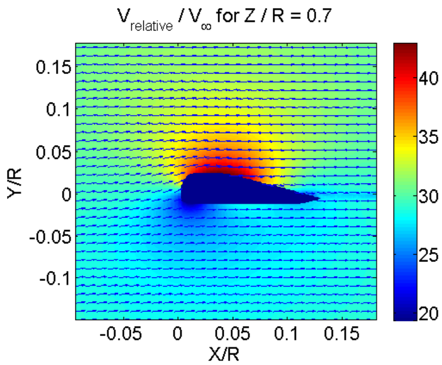
The velocity fields of the different cross sectional planes of a horizontal axis wind turbine working in axial flow condition have been inspected by means of the stereoscopic PIV technique. These 3D velocity measurements bring a better understanding of the flow phenomena in each of the elements of the rotating blade and represent a way of reconstruction of the pressure field around the airfoils without the need of pressure tabs and their inherent set up complexity. Furthermore, they provide the means for calculating the aerodynamic forces impinged on each section of the wind turbine.

Data analyzed herein were acquired at the Open Jet Facility at TU Delft from a two bladed upwind rotor, 2 m in diameter, operating at $\Omega = 400\,\text{rpm}$ and tip speed ratio $\lambda = 7$. Phase locked 3D PIV velocity measurements were obtained at cross sectional positions of the blade, spaced 10mm to 30mm spanwise between each other, from the tip to the root. The pressure field was obtained by solving the Poisson equation in all the flow field. The momentum equation expressed in a 3D formulation and integrated around a control volume was used to infer the forces executed on each radial radial position. The non inertial frame of reference was mounted on the blade itself, thus providing a steady case problem for axial flow conditions.

As a result, the aerodynamic loads exerted on the wind turbine blade were calculated and found good agreement with the predictions of the vortex lattice panel code implemented at TU Delft; in particular, the thrust matched perfectly with that predicted by the numerical code. The induced axial and radial velocities contained in each cross sectional were measured. Moreover, tip and hub vortexes as well as the vorticity induced by the previous wake were observed in the fields studied, fact that could also be noticed in the different results obtained in the reconstruction of the pressure field using alternatively potential and non potential formulation.

The conclusions of the project proved the feasibility of measuring wind loads in each blade element through PIV. The results achieved give a better insight into the aerodynamics of horizontal axis wind turbines, allowing to study what are the flow phenomena that take place in each span position and what are their contributions to the global torque. The methodology also constitutes a means of validation for numerical models and could bring a new way of studying rotational effects and the efficiency of active load control implementations.

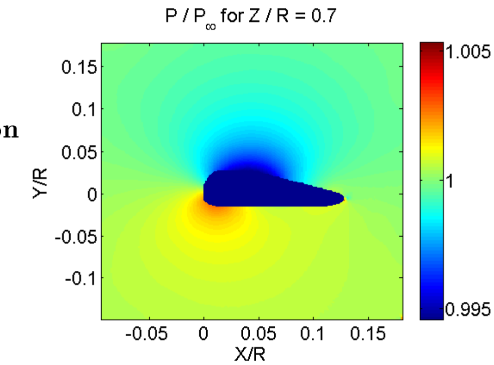
NOTE FOR REVIEWER: Next pages show additional figures depicting research results and methodology.



Relative Velocity Field at $z/R = 0.7$

Momentum Equation

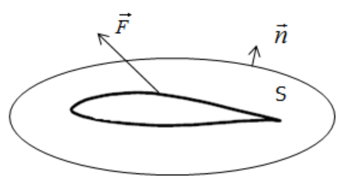
$$\nabla p = \rho \frac{\mathrm{D}\vec{V}}{\mathrm{D}t} + \nabla \cdot \bar{\bar{\tau}}'$$

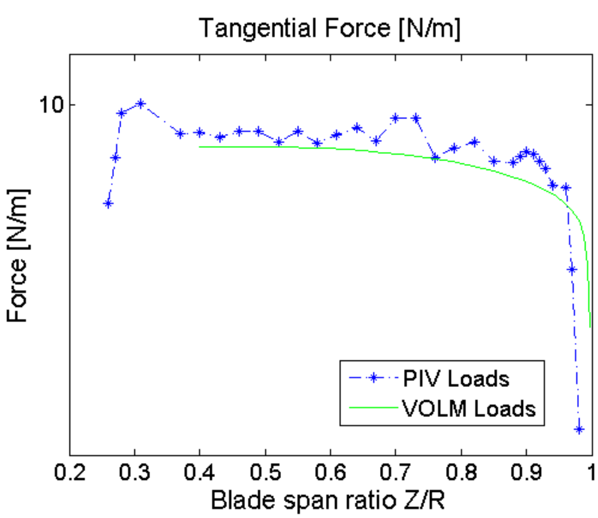


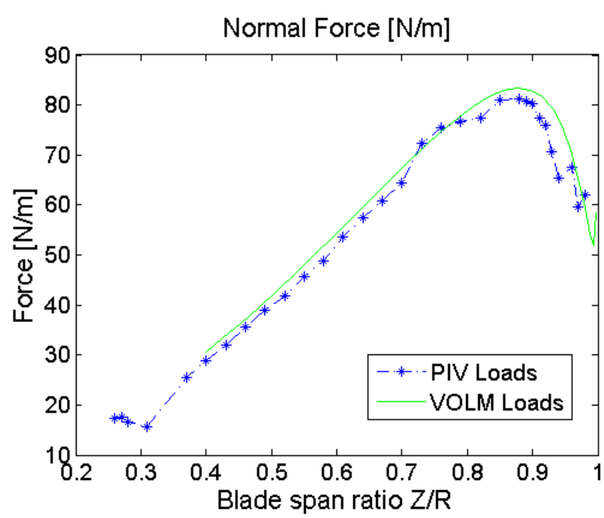
Pressure Field at $z/R = 0.7$

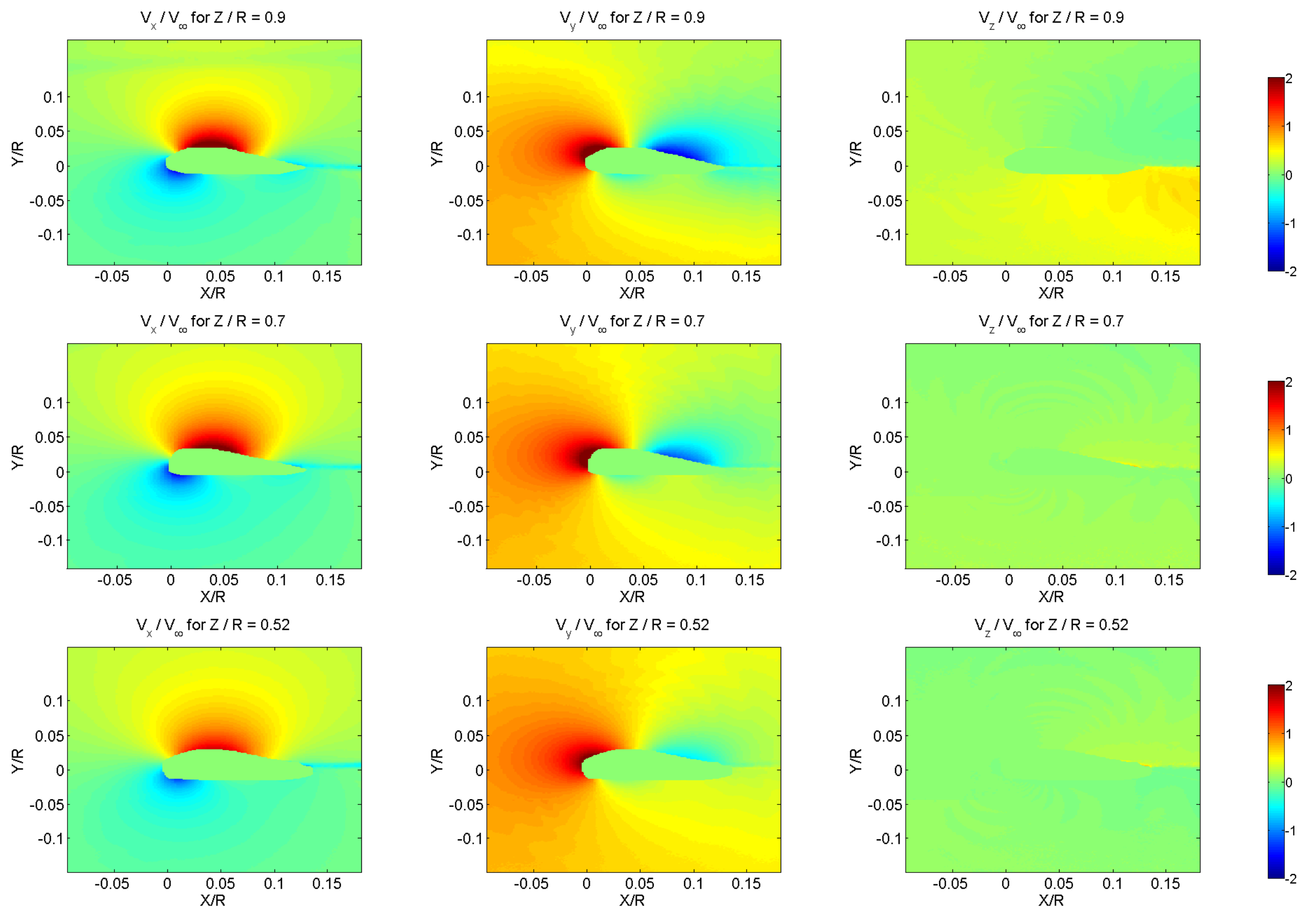
Contour Approach

$$\overrightarrow{F} = -\iiint_v \frac{\partial \overrightarrow{V}}{\partial t} \mathrm{d}v - \iint_s \rho \left(\overrightarrow{V} \cdot \overrightarrow{n} \right) \overrightarrow{V} \mathrm{d}s + \iint_s \left(-p\overrightarrow{n} + \tau' \overrightarrow{\overline{\overline{n}}} \right) \mathrm{d}s$$









Absolute velocity fields for different span positions of the blade